U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE

HEARING CHARTER

Should Congress Establish "ARPA-E," The Advanced Research Projects Agency – Energy?

Thursday, March 9, 2006

1. Purpose

On Thursday, March 9, 2006, the House Committee on Science will hold a hearing on whether Congress should establish an Advanced Research Projects Agency in the Department of Energy, or an ARPA-E.

The National Academy of Sciences, in its report last fall on enhancing American competitiveness, *Rising Above the Gathering Storm*, recommended the creation of an ARPA-E to fund "transformational research that could lead to new ways of fueling the nation and its economy," and different bills have been introduced in the House and Senate to implement the recommendation.

Critics of the proposal have raised a variety of issues, including that an ARPA-E may not address the actual barriers to new energy technology; that it is based on a research agency model that does not apply well to energy; that different proponents of ARPA-E describe different missions for it; that it would compete with, or get swallowed up by existing energy research programs; and that it is unclear how it would be distinct from other energy research programs.

The hearing is intended to help Congress analyze the arguments for and against an ARPA-E, to consider alternative approaches, and to determine how to structure an ARPA-E if it were created.

2. Witnesses

Dr. Steven Chu is Director of Lawrence Berkeley National Laboratory. He served on the NAS panel[1] that recommended establishing ARPA-E. He was a co-winner of the 1997 Nobel Prize in Physics.

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[1] Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology which produced the October 2005 NAS report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, The National Academies Press, Washington, DC (2005).

Dr. Catherine Cotell is Vice President for Strategy, University and Early Stage Investment at In-Q-Tel. The Central Intelligence Agency established In-Q-Tel in 1999 to gain access to new technologies emerging from small startup companies.

Dr. Frank L. Fernandez is President of F. L. Fernandez, Inc., a consulting firm with clients in research and development. He served as Director of the Defense Advanced Research Projects Agency (DARPA) from 1998 to 2001.

Ms. Melanie Kenderdine is Vice President, Washington Operations, for the Gas Technology Institute. She served as Director of the Office of Policy in the Department of Energy from 1999 to 2000.

Dr. David Mowery is the William A. & Betty H. Hasler Professor of New Enterprise Development at the Haas School of Business, University of California at Berkeley. He is an expert in technological change, international trade, and U.S. technology policy.

3. Overarching Questions

- What problems within the energy research enterprise is ARPA-E intended to address? Is ARPA-E the best mechanism to address these problems? If not, what alternatives might be more successful?
- If Congress were to create an ARPA-E, how should the agency operate, where in the Department of Energy (DOE) should it be located, and how should it interact with existing aspects of DOE, including the National Laboratories?

4. Brief Overview

The October 2005 NAS report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (also known as the Augustine Report for its chair, retired Lockheed Martin CEO Norman Augustine), recommended creating an ARPA-E within DOE to fund "transformational research that could lead to new ways of fueling the nation and its economy." The report offered recommendations in four areas to enhance U.S. competitiveness: K-12 education, higher education, economic and technology policy, and scientific research.

The Augustine report argued that affordable and reliable energy production is central to the future of the American economy and that revolutionary new technologies are needed for a sustainable energy future. The report argued further that no existing DOE programs were well suited to promote such technological advances and get them into the marketplace. What was needed, the report concluded was a DOE unit modeled on the Defense Advanced Research Projects Agency (DARPA), the agency that is widely credited with the development of the Internet. The Augustine report said ARPA-E:

> would sponsor creative, out-of-the-box, transformational, generic energy research in those areas where industry by itself cannot or will not undertake such sponsorship, where risks and potential payoffs are high, and where success could provide dramatic benefits for the nation. ARPA-E would accelerate the process by which research is transformed to

> address economic, environmental, and security issues. It would be designed as a lean, effective, and agile—but largely independent—organization that can start and stop targeted programs based on performance and ultimate relevance.

Citing the Augustine report, the President has proposed increased funding for three research and development (R&D) agencies and for several science and math education programs. The Administration has not endorsed the ARPA-E proposal and has expressed concern that its funding could compete with higher priorities, including proposed increases for DOE's Office of Science. Energy Secretary Samuel Bodman has suggested that an entity based on In-Q-Tel, a venture capital organization sponsored by the Central Intelligence Agency (CIA), might be a more appropriate approach to getting new technology into the energy market. (More on that below.)

5. Issues

The arguments for ARPA-E are laid out in the Augustine report (excerpt attached). This section summarizes the arguments of critics.

Why aren't more revolutionary technologies finding their way into the energy market, and is ARPA-E an effective approach to solving that problem? This is really two questions: First, is the problem in the energy markets primarily one to be solved by increasing the supply of energy technologies or by creating more demand for energy technologies? And second, if the problem is the supply of technologies, would ARPA-E be the most effective way to spawn new technologies and get them into the marketplace?

Is the problem primarily one of technology supply or demand? While there is no question that R&D is necessary to supply new technologies to the marketplace, some critics of the ARPA-E proposal argue that the U.S. energy marketplace is not short of ideas or technologies, but that the current market structure does not generate demand for new technologies. For example, an NAS study several years ago identified numerous existing technologies that could increase automobile fuel mileage that were not being applied or applied for that purpose. Even today, oil prices are generally at a level that does not induce consumers to switch to new energy technologies. Without government incentives, whether through taxes, regulations or other means, the market will not create a sufficient for demand for new technologies, these critics argue. They point out that while there are societal reasons to seek new energy technologies, those do not translate into individual demands with oil at current prices. Under this reasoning, new technologies funded by an ARPA-E are no more likely to find their way into the marketplace than are existing ideas.

What is the primary barrier to technology supply and would ARPA-E address it? But even if one assumes that technology supply is part of the problem, ARPA-E, may not be the most effective tool to get more new technologies into the marketplace, critics argue. According to the Augustine report, ARPA-E would fund "a broad portfolio of foundational research that is needed to invent transforming technologies that in the past

were often supplied by our great industrial laboratories." This assumes that a primary gap in energy technology creation is a lack of early-stage, largely basic research and that the government would be able to determine what kind of research in that area is most needed. But many advocates of a greater government role in energy technology see the primary barrier not at the early stages of research, but later in the process when the inventors of new technologies find that they do not have the wherewithal to fully develop their ideas into products or to bring their ideas to market. Some advocates of ARPA-E who were not on the Academy panel argue that ARPA-E could address this stage of the problem, but that is not what the Academy has argued. Critics argue that if the goal is to work on the later stages of development and product introduction, then an ARPA-E is the wrong tool to use.

Does the DARPA model match the needs of energy R&D? Proponents of new government efforts to get R&D into the marketplace often turn to DARPA as a model. For example, in the competitiveness debates of the 1980s, some argued for the creation of a civilian equivalent of DARPA to counter Japanese inroads in U.S. technology markets. (This proposal contributed to the creation of the Department of Commerce's Advanced Technology Program.) In the Homeland Security Act, Congress created a Homeland Security Advanced Projects Agency (HSARPA) to help create new technologies to counter terrorism. HSARPA is not generally viewed as a success, partly because it has focused primarily on short-term development projects.

The appeal of the DARPA model is clear. DARPA has had an enviable record of success in funding technologies that have given the U.S. military a technology edge, many of which have eventually made it into the marketplace. Experts generally attribute the agency's success to its relative independence from the military services and their laboratories, its ties to industry as well as academia, its relative insulation from politics which has enabled the agency in the past to undertake long-range projects and tolerate failure, and its internal structure which empowers program managers to make decisions on who and what to fund. Like the National Science Foundation (NSF), DARPA performs no research, but funds research elsewhere. Unlike NSF, DARPA works more with industry and does not have peer review of its proposals. But DARPA has had its ups and downs and has focused on different aspects of technology over its almost 50 years of operation. Today, DARPA is focusing more on shorter-range projects of more immediate use to the military.

Critics of the ARPA-E proposal argue that a salient feature of DARPA is that it funds the creation of technologies for which the government will be the primary or sometimes sole market. This makes it easier to determine what technologies to target, helps researchers target their own efforts, and assures industry that there will be a payoff for its efforts. Moreover, price is not generally a significant consideration for technologies developed by DARPA. This is true in the area of homeland security, as well. But this fundamental feature of DARPA is not true in the energy arena. Critics argue that it is at best unclear how a DARPA model would succeed in a field in which the government is not a primary customer and does not exert much direct control over the marketplace.

What other models exist that could be applied to energy research? Another model that has been suggested to push more technology into the energy market is In-Q-Tel, a Congressionally created, government-funded non-profit venture capital firm that seeks to accelerate market introduction of products that could benefit U.S. intelligence efforts. In-Q-Tel generally does not get involved in technologies until they are well on their way to development or in the prototype stage. Therefore, In-Q-Tel would not help attack the problem that the Augustine report identified, a lack of early-stage, more fundamental research. But an In-Q-Tel model might get more ideas out of the laboratory and into the marketplace. However, In-Q-Tel, like DARPA, works in a realm in which the government is the market. While In-Q-Tel will only back ventures that appear to have a market beyond the government, its primary goal is to promote the development of products that the government itself will purchase. Also, In-Q-Tel, which was created in 1998 and did not get fully underway until later, does not yet have much of a track record and no one has analyzed how it might function in the energy market. Moreover, the expanding use of government-funded firms that get equity in private companies could raise questions about the appropriate government role in the financial marketplace.

Why can't existing DOE programs accomplish the goal of an ARPA-E and how would an ARPA-E interact with existing programs? Proponents of ARPA-E argue, in effect, that the DOE Office of Science programs are too basic and that the DOE energy supply programs are too applied, leaving a gap. The Office of Science does support fundamental research, but most of it is not directed at specific energy problems or technologies. (The Office of Science is trying to increase its involvement in these areas.) The applied programs tend to fund incremental research that is unlikely to lead to "transformational" advances. DOE also has a more bureaucratic culture than DARPA and lacks some of DARPA's more flexible procurement authority.

Some critics argue that DOE should reform its basic and/or applied programs to address any gaps identified by the Academy report. Others fear that if an ARPA-E is located in DOE it will be gradually come to look like existing DOE programs because otherwise it will compete with them for funds. These critics are particularly fearful that ARPA-E will simply become another source of funding for the National Laboratories, which they see as too removed from the marketplace and too focused on their existing portfolios to undertake "transformational" research targeted at new energy technologies. These critics note that a strength of DARPA has been that is has not had its own laboratories and has generally worked independently of the military laboratories.

How would an ARPA-E be structured? The Academy panel did not provide detailed advice on how to structure ARPA-E, other than to point to the DARPA model. In establishing an ARPA-E, Congress would have to decide where in DOE to locate it, how to ensure the independent and program manager-driven agenda of DARPA, how to provide stable and adequate funding and how to clearly describe the kinds of research that ARPA-E would be intended to fund. The Augustine report recommends having ARPA-E report to the DOE Under Secretary for Science (a position created by last summer's *Energy Policy Act*), but critics worry that that would not give ARPA-E adequate independence and would increase the likelihood that funds would go to the

National Laboratories. Some critics argue that if Congress were to create an ARPA-E, it should do so outside of DOE and perhaps as a free-standing quasi-governmental entity.

6. Additional Background

Augustine Report. The Academy panel did not receive outside advice or testimony on the ARPA-E idea and at least one of its members was a reluctant supporter of the idea because of concerns that the DARPA model did not apply to areas in which the government was not a customer. Also, the one member of the Academy panel from the energy industry, Lee Raymond, then-Chairman and CEO of the Exxon Mobil Corporation, dissented from the recommendation, arguing against further government involvement in energy markets.

History and Structure of DARPA. DARPA's mission is "to prevent technological surprise to the US, but also to create technological surprise for our enemies,"[2] through radical innovation to further national security. While each service branch conducts its own research to further known, short-term requirements, DARPA aims to anticipate future military needs, in any service branch, and accelerate development of breakthrough technology to meet those needs.

DARPA was created in 1958 as the Advanced Research Projects Agency (ARPA), in response to Cold War concerns such as the launch of Sputnik Early areas of research involved space and missile defense. By the late 1970's, the agency focused on defense, emphasizing breakthrough technological applications and enhanced links to real customers. ARPA/DARPA research projects include crucial contributions to development of stealth aircraft, unmanned aerial vehicles (UAVs), and the Internet.

DARPA exists within the Office of the Secretary of Defense, outside the service branches. Its director oversees Offices (eight of them at present) that bring together experts with similar interests. Within the Offices are program managers hired for short stints, typically four to six years. Only one layer of management, the Office directors, separates the program managers from the director. DARPA upper management devise research themes in consultation with defense leaders, and together with the program managers, they identify important, difficult problems that fit in with those themes. Program managers are expected to consult with technical communities throughout government, industry, and academia to design projects intended to create novel military capabilities. Program managers have special contracting authority that allows them to negotiate flexible contracting arrangements with researchers. Their projects aim to create usable products, and must include plans for transfer of those products to real users. The short term of program managers creates a supply of new people with new ideas and encourages accelerated execution of projects. DARPA has no laboratories of its own—all work is performed by contract with outside researchers—minimizing institutional interests within DARPA that might prolong research that is no longer promising.

[2] *DARPA: Bridging the Gap; Powered by Ideas*, Defense Advance Research Projects Agency, Feb. 2005, p. 1

DARPA strives to transfer its research products to actual warfighters. This transfer may occur for research that leads to a component technology—such as a stealth technology or microchip—that a defense contractor incorporates the component into larger system that it ultimately sells to a service branch. Because DARPA relies on outside research laboratories, the contractor itself may have participated in the development of the technology, acquiring enough familiarity and confidence in it to use it in a real product it sells to a service branch.

The transfer of technology from DARPA to a service branch may be more challenging, however, for a more elaborate technology. The technology might compete with a significant existing technology already in use by a service. Furthermore, because DARPA looks beyond known, short-term, technological needs, its technology may demand new methods for employing the technology. As a result, a service branch may resist acquiring the DARPA technology. To overcome this resistance, DARPA can appeal directly to the Secretary of Defense, since its position within DOD does not require reporting through the service branches.

History and Structure of In-Q-Tel. In-Q-Tel started off making investments primarily in the information technology area, including Internet security, data integration, imagery analysis, and language translation, and in recent years has expanded into infrastructure priorities such as wireless communications and nanotechnology, and biodefense products such as sensors. These investments have helped government agencies keep up with technology developments in the commercial marketplace, and helped the intelligence community in particular to mold, develop and deploy crucial technologies in a timely manner.

To keep up with the boom in innovations in the private sector, especially in information technology (IT), the CIA assembled a team of senior staff and outside consultants and lawyers in 1998 to design an entity to partner with industry in accelerated solutions to IT problems facing the intelligence community. After meeting with investment bankers, venture capitalists, entrepreneurs, and Members of Congress and staff, the team conceived what is now In-Q-Tel.

In-Q-Tel actively seeks out emerging technology that can help meet the needs of its intelligence agency clients. Its primary means of involvement with fledgling technologies is to invest in the companies developing the technology alongside of commercial investment partners, using the equity tool, combined with a great deal of contractual flexibility, to provide In-Q-Tel and its government partners early access to the technology and the ability to influence product development.

Small or newer companies often do not to target the federal government market because it can be difficult to target or slow to access. And because those companies often need to penetrate their markets quickly to generate cash flow, government customers can miss the chance to influence product development. Moreover, private venture capital firms sometimes discourage small companies they invest in from doing business with the

government because the complexity of the procurement process and long lead time on procurement decisions. This means that agencies are often two to three years behind the commercial market for technology, especially in areas like IT where there is rapid innovation.

Through special flexibility in contracting arrangements granted by Congress similar to the flexibility enjoyed by DARPA in its arrangements, In-Q-Tel is able to overcome procurement obstacles and to help the intelligence agencies adopt technology more quickly. However, in the long run, In-Q-Tel believes that the products it invests in should be targeted at a commercial market, to lower costs for its client agencies, and that they should be purchased through normal procedures once fully commercialized.

A Board of Trustees oversees In-Q-Tel's direction, strategy, and policies.[3] In-Q-Tel is managed by a CEO and has a staff of 64. Its current budget is estimated to be $60 million.[4] In-Q-Tel seeks to demonstrate solutions. It does not generate finished products. The CIA or other intelligence agencies acquire products through their own separate contracting arrangements. Although In-Q-Tel operations are public and few of their staff have security clearance, the manner of actual use of their products by the CIA may be classified. Nonetheless, In-Q-Tel offers the CIA a mechanism by which to involve industry in solving the specific technology problems faced by the intelligence community.

7. Legislative Proposals.

H.R. 4435 (Gordon): A bill to provide for the establishment of the Advanced Research Projects Agency-Energy

This bill establishes the Advanced Research Projects Agency - Energy (ARPA-E) within DOE. This new agency is modeled after DARPA. Under the bill, ARPA-E is headed by a Director appointed by the Secretary. The Director hires program managers to manage individual projects, and the project managers are given flexibility in establishing R&D goals for the program. Program managers will also be responsible for selecting projects for support as well as monitoring their progress. The ARPA-E will have authority to hire specialized science and engineering personnel to be program managers. Participation in the program is limited to institutions of higher education, companies or consortia of universities and companies, and these consortia may also include federally funded research and development centers.

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[3] Among its trustees is Norman Augustine, chair of the committee that produced the NAS *Rising Above the Gathering Storm* report. In an August 15, 2005 Washington Post article, Augustine called In-Q-Tel "far more successful than [he] thought it would be," but "still an unproved experiment."

[4] *Tech Entrepreneur Joins CIA's Venture Capital Arm*, Washington Post, January 4, 2006. http://www.washingtonpost.com/wp-dyn/content/article/2006/01/03/AR2006010301401.html

In addition, the bill establishes an Energy Independence Acceleration Fund, allows for recoupment of funds from successful commercialization projects, and includes provisions relating to an Advisory Committee and evaluation of ARPA-E.

S. 2197 (Domenici/Bingaman/Alexander/Mikuski): Protecting America's Competitive Edge through Energy Act of 2006, known as the "PACE-Energy" Act

Section 4 of this bill, which will be marked up on March 8, creates ARPA-E, using language based on the law that created the Homeland Security Advanced Resarch Projects Agency. Under the bill, ARPA-E is a new office within DOE that will report to the Undersecretary for Science.

S. 2196 (Clinton/Reid/Bingaman): Advanced Research Projects Energy Act

This bill establishes the Advanced Research Projects Agency – Energy within the Department of Energy. The provisions of this bill also include prizes for advanced technology achievements, annual reporting requirements, and authorizations.

6. Witness Questions

<u>Dr. Steve Chu, Dr. Fernando L. Fernandez, Ms. Melanie Kenderdine, and Dr. David Mowery</u>

1) Should ARPA-E be designed more to foster directed basic research or to get products into the marketplace? If the focus were basic research, what steps would ARPA-E or other entities have to take to affect the marketplace? If the focus were technology transfer, what specific barriers would ARPA-E be designed to overcome, how would it do so, and would that be the most effective way that government could transform the energy marketplace?

2) What kinds of entities should receive funding from ARPA-E? Should the National Laboratories be able to receive funding from ARPA-E? How should the work funded by ARPA-E differ from work funded under existing DOE basic and applied research programs? How could Congress structure ARPA-E to ensure that ARPA-E did not end up carrying out programs that are substantially similar to those already in DOE's portfolio?

3) Is it credible to develop a solution to U.S. energy needs based on the Defense Advanced Research Projects Agency (DARPA), given that DARPA is developing ideas for a market in which the government itself is the primary customer and cost is not a primary concern?

<u>Dr. Catherine Cotell</u>

1) How far along in the research and development process are the products and processes that In-Q-Tel supports? To what extent has government research

funding contributed to the products and processes that In-Q-Tel supports? How would you contrast In-Q-Tel's role with that of the Defense Advanced Research Projects Agency (DARPA)?

2) To what extent do you think the In-Q-Tel model could be applied to areas in which the government is not going to be a primary or early user of a technology? What practical and/or philosophical questions would such an expansion of the In-Q-Tel model raise?

3) What have you found to be the primary barriers to new technologies coming to market? Does the U.S. seem to have more of a problem creating new technologies or bringing them to market? Do you think the same factors are the primary barriers in the energy market?

Appendix 1
ARPA-E Proposal Excerpted from *Rising Above the Gathering Storm*

ACTION B-5: Use DARPA As a Model for Energy Research

The federal government should create a DARPA-like organization within the Department of Energy called the Advanced Research Projects Agency-Energy (ARPA-E) that reports to the under secretary for science and is charged with sponsoring specific R&D programs to meet the nation's long-term energy challenges.[5]

Perhaps no experiment in the conduct of research and engineering has been more successful in recent decades than the Defense Advanced Research Projects Agency model. The new agency proposed herein is patterned after that model and would sponsor creative, out-of-the-box, transformational, generic energy research in those areas where industry by itself cannot or will not undertake such sponsorship, where risks and potential payoffs are high, and where success could provide dramatic benefits for the nation. ARPA-E would accelerate the process by which research is transformed to address economic, environmental, and security issues. It would be designed as a lean, effective, and agile—but largely independent—organization that can start and stop targeted programs based on performance and ultimate relevance. ARPA-E would focus on specific energy issues, but its work (like that of DARPA or NIH) would have significant spinoff benefits to national, state, and local government; to industry; and for the education of the next generation of researchers. The nature of energy research makes it particularly relevant to producing many spin off benefits to the broad fields of engineering, the physical sciences, and mathematics, fields identified in this review as warranting special attention. Existing programs with similar goals should be examined to ensure that the nation is optimizing its investments in this area. Funding for ARPA-E would begin at $300 million for the initial year and increase to $1 billion over 5 years, at which point the program's effectiveness would be reevaluated. The committee picked this level of funding the basis of on its review of the budget history of other new research activities and the importance of the task at hand.

[5] One committee member, Lee Raymond, shares the alternative point of view on this recommendation as summarized in Box 6-3.

The United States faces a variety of energy challenges that affect our economy, our security, and our environment (see Box 6-4). Fundamentally, those challenges involve science and technology. Today, scientists and engineers are already working on ideas that could make solar and wind power economical; develop more efficient fuel cells; exploit energy from tar sands, oil shale, and gas hydrates; minimize the environmental consequences of fossil-fuel use; find safe, affordable ways to dispose of nuclear waste; devise workable methods to generate power from fusion; improve our aging energy-distribution infrastructure; and devise safe methods for hydrogen storage.[6]

ARPA-E would provide an opportunity for creative "out-of-the box" transformational research that could lead to new ways of fueling the nation and its economy, as opposed to incremental research on ideas that have already been developed. One expert explains, "The supply [of fossil-fuel sources] is adequate now and this gives us time to develop alternatives, but the scale of research in physics, chemistry, biology and engineering will need to be stepped up, because it will take sustained effort to solve the problem of long-term global energy security."[7]

Although there are those who believe an organization like ARPA-E is not needed (Box 6-3), the committee concludes that it would play an important role in resolving the nation's energy challenges; in advancing research in engineering, the physical sciences, and mathematics; and in developing the next generation of researchers. A recent report of the Secretary of Energy Advisory Board's Task Force on the Future of Science Programs at the Department of Energy notes, "America can meet its energy needs only if we make a strong and sustained investment in research in physical science, engineering, and applicable areas of life science, and if we translate advancing scientific knowledge into practice. The current mix of energy sources is not sustainable in the long run."[8] Solutions will require coordinated efforts among industrial, academic, and government laboratories. Although industry owns most of the energy infrastructure and is actively developing new technologies in many fields, national economic and security concerns dictate that the government stimulate research to meet national needs. These needs include neutralizing the provision of energy as a major driver of national security concerns. ARPA-E would invest in a broad portfolio of foundational research that is needed to invent transforming technologies that in the past were often supplied by our great industrial laboratories (see Box 6-5). Funding of research underpinning the provision of new energy sources is made particularly complex by the high cost, high risk and long-term character of such work—all of which make it less suited to university or industry funding.

Among its many missions, DoE promotes the energy security of the United States, but some of the department's largest national laboratories were established in wartime and given clearly defense-oriented missions, primarily to develop nuclear weapons. Those weapons laboratories, and some of the government's other large science laboratories, represent significant national investments in personnel, shared facilities, and knowledge. At the end of the Cold War, the nation's defense needs shifted and urgent new agendas became clear—development of clean sources of energy, new forms of transportation, the provision of homeland security, technology to speed environmental remediation, and technology for commercial application. Numerous proposals over recent years have laid the foundation for more extensive redeployment of

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[6] M. S. Dresselhaus and I. L. Thomas. Alternative energy technologies. *Nature* 414(2001):332-337.
[7] Ibid.
[8] Secretary of Energy's Advisory Board, Task Force on the Future of Science Programs at the Department of Energy. Critical Choices: Science, Energy and Security. Final Report. Washington, DC: U.S. Department of Energy, Oct. 13, 2003, p. 5.

national laboratory talent toward basic and applied research in areas of national priority.[9]

[9] Galvin Panel report, *Task Force on Alternative Futures for the Department of Energy National Laboratories*, Secretary of Energy Advisory Board. Washington, DC.: U.S. Department of Energy, Feb. 1995; PCAST, *Federal Energy Research and Development for the Challenges of the Twenty-First Century*, Report of the Energy Research and Development Panel, the President's Committee of Advisors on Science and Technology, Washington, DC, Nov. 1997; Government Accounting Office. *Best Practices: Elements Critical to Successfully Reducing Unneeded RDT&E Infrastructure.* USGAO Report to Congressional Requesters. Washington, DC: GAO **(?)**, Jan. 8 1998.

BOX 6-3
Another Point of View: ARPA-E

Energy issues are potentially some of the most profound challenges to our future prosperity and security, and science and technology will be critical in addressing them. But not everyone believes that a federal program like the proposed ARPA-E would be an effective mechanism for developing bold new energy technologies. This box summarizes some of the views the committee heard about ARPA-E from those who disagree with its utility.

Some believe that such applied energy research is already well funded by the private sector—by large energy companies and, increasingly, by venture capital firms—and that the federal government should fund only basic research. They argue that there is no shortage of long-term research funding in energy, including that sponsored by the federal government. DOE is the largest individual government supporter of basic research in the physical sciences, providing more than 40% of associated federal funding. DOE provides funding and support to researchers in academe, other government agencies, nonprofit institutions, and industry. The government spends substantial sums annually on research, including $2.8 billion on basic research and on numerous technologies. Given the major investment DOE is already making in energy research, it is argued that if additional federal research is desired in a particular field of energy, it should be accomplished by reallocating and optimizing the use of funds currently being invested.

It is therefore argued that no additional federal involvement in energy research is necessary, and given the concerns about the apparent shortage in scientific and technical talent, any short-term increase in federally directed research might crowd out more productive private-sector research. Furthermore, some believe that industry and venture capital investors will already fund the things that have a reasonable probability of commercial utility (the invisible hand of the free markets at work), and what is not funded by existing sources is not worthy of funding.

Another concern is that an entity like ARPA-E would amount to the government's attempt to pick winning technologies instead of letting markets decide. Many find that the government has a poor record in that arena. Government, some believe, should focus on basic research rather than on developing commercial technology.

Others are more supportive of DOE research as it exists and are concerned that funding ARPA-E will take money away from traditional science programs funded by DOE's Office of Science in high-energy physics, fusion energy research, material sciences, and so forth that are of high quality and despite receiving limited funds produce Nobel-prize-quality fundamental research and commercial spin offs. Some believe that DOE's model is more productive than DARPA's in terms of research quality per federal dollar invested.

Introducing a small, agile, DARPA-like organization could improve DoE's pursuit of R&D much as DARPA did for the Department of Defense. Initially, DARPA was viewed as "threatening" by much of the department's established research organization; however, over the years it has been widely accepted as successfully filling a very important role. ARPA-E would identify and support the science and technology critical to our nation's energy infrastructure. It also could offer several important national benefits:

- Promote research in the physical sciences, engineering, and mathematics.
- Create a stream of human capital to bring innovative approaches to areas of national strategic importance.
- Turn cutting-edge science and engineering into technology for energy and environmental applications.
- Accelerate innovation in both traditional and alternative energy sources and in energy-efficiency mechanisms.
- Foster consortia of companies, colleges and universities, and laboratories to work on critical research problems, such as the development of fuel cells.

The agency's basic administrative structure and goals would mirror those of DARPA, but there would be some important differences. DARPA exists mainly to provide a long-term "break-through" perspective for the armed forces. DoE already has some mechanisms for long-term research, but it sometimes lacks the mechanisms for transforming the results into technology that meets the government's needs. DARPA also helps develop technology for purchase by the government for military use. By contrast, most energy technology is acquired and deployed in the private sector, although DoE does have specific procurement needs. Like DARPA, ARPA-E would have a very small staff, would perform no R&D itself, would turn over its staff every 3 to 4 years, and would have the same personnel and contracting freedoms now granted to DARPA. Box 6-6 illustrates some energy technologies identified by the National Commission on Energy Policy as areas of research where federal research investment is warranted that is in research areas in which industry is unlikely to invest.

BOX 6-4 Energy and the Economy

Capital, labor, and energy are three major factors that contribute to and influence economic growth in the United States. Capital is the equipment, machinery, manufacturing plants, and office buildings that are necessary to produce goods and services. Labor is the availability of the workforce to participate in the production of goods and services. Energy is the power necessary to produce goods and services and transport them to their destinations. These three components are used to compute a country's gross domestic product (GDP), the total of all output produced in the country. Without these three inputs, business and industry would not be able to transform raw materials into goods and services.

Energy is the power that drives the world's economy. In the industrialized nations, most of the equipment, machinery, manufacturing plants, and office buildings could not operate without an available supply of energy resources such as oil, natural gas, coal, or electricity. In fact, energy is such an important component of manufacturing and production that its availability can have a direct impact on GDP and the overall economic health of the United States.

Sometimes energy is not readily available because the supply of a particular resource is limited or because its price is too high. When this happens, companies often decrease their production of goods and services, at least temporarily. On the other hand, an increase in the availability of energy—or lower energy prices—can lead to increased economic output by business and industry.

Situations that cause energy prices to rise or fall rapidly and unexpectedly, as the world's oil prices have on several occasions in recent years, can have a significant impact on the economy. When these situations occur, the economy experiences what economists call a "price shock". Since 1970, the economy has experienced at least four such price shocks attributable to the supply of energy. Thus, the events of the last several decades demonstrate that the price and availability of a single important energy resource—such as oil—can significantly affect the world economy.

SOURCE: Adapted from Dallas Federal Reserve Bank at www.dallasfed.org/educate/everyday/ev2.html.

Box 6-5: The Invention of the Transistor

In the 1930s, the management of Bell Laboratories sought to develop a low-power, reliable, solid-state replacement for the vacuum tube used in telephone signal amplification and switching. Materials scientists had to invent methods to make highly pure germanium and silicon and to add controlled impurities with unprecedented precision. Theoretical and experimental physicists had to develop a fundamental understanding of the conduction properties of this new material and the physics of the interfaces and surfaces of different semiconductors. By investing in a large-scale assault on this problem, Bell announced the “invention” of the transistor in 1948, less than a decade after the discovery that a junction of positively and negatively doped silicon would allow electric current to flow in only one direction. Fundamental understanding was recognized to be essential, but the goal of producing an economically successful electronic-state switch was kept front-and-center. Despite this focused approach, fundamental science did not suffer: a Nobel prize was awarded for the invention of the transistor. During this and the following effort, the foundations of much of semiconductor-device physics of the 20th century were laid.

BOX 6-6
Illustration of Energy Technologies

The National Commission on Energy Policy in its December 2004 report *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges* recommended doubling the nation's annual direct federal expenditures on "energy research, development, and demonstration" (ERD&D) to identify better technologies for energy supply and efficient end use. Improved technologies, the commission indicates, will make it easier to

- Limit oil demand and reduce the fraction of it met from imports without incurring excessive economic or environmental costs
- Improve urban air quality while meeting growing demand for automobiles
- Use abundant US and world coal resources without intolerable impacts on regional air quality and acid rain
- Expand the use of nuclear energy while reducing related risks of accidents, sabotage, and proliferation.
- Sustain and expand economic prosperity where it already exists—and achieve it elsewhere—without intolerable climatic disruption from greenhouse-gas emissions.

The commission identified what it believes to be the most promising technological options where private sector research activities alone are not likely to bring them to that potential at the pace that society's interests warrant. They fall into the following principal clusters:

- **Clean and efficient automobile and truck technologies**, including advanced diesels, conventional and plug-in hybrids, and fuel-cell vehicles

- **Integrated-gasification combined-cycle coal technologies** for polygeneration of electricity, steam, chemicals, and fluid fuels

- **Other technologies that achieve, facilitate, or complete carbon capture and sequestration**, including the technologies for carbon capture in hydrogen production from natural gas, for sequestering carbon in geologic formations, and for using the produced hydrogen efficiently

- **Technologies to efficiently** produce biofuels for the transport sector

- **Advanced nuclear technologies** to enable nuclear expansion by lowering cost and reducing risks from accidents, terrorist attacks, and proliferation

- **Technologies for increasing the efficiency of energy end use in buildings and industry**.